Coupling Between Adjacent Finite Ground Coplanar (FGC) Waveguides

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Abstract

Coupling between adjacent Finite Ground Coplanar (FGC) waveguides as a function of the line geometry is presented for the first time. A two Dimension-Finite Difference Time Domain (2D-FDTD) analysis and measurements are used to show that the coupling decreases as the line to line separation and the ground plane width increases. Furthermore, it is shown that for a given spacing between the center lines of two FGC lines, the coupling is lower if the ground plane width is smaller.

Key words: Coplanar waveguide, finite ground coplanar waveguide, coupled transmission lines, microwave transmission lines

Introduction

Coplanar Waveguide (CPW) is often used for microwave and millimeter-wave integrated circuits because both series and shunt circuit elements may be easily integrated without costly via hole and back side wafer processing, but when CPW is placed in a package, it has several problems. The package introduces a ground plane on the back side of the wafer that establishes a parallel plate waveguide as shown in Figure 1. Since the parallel plate waveguide mode has a lower phase velocity than the CPW mode over the entire frequency spectrum, energy leaks from the CPW mode to the parallel plate waveguide mode. Energy in the parallel plate waveguide mode creates resonances that severely degrade the CPW circuit characteristics when the size of the circuit is greater than $\lambda_d/2$ where λ_d is the wavelength in the dielectric [1], [2].

Via holes may be used to electrically short the upper and lower ground planes to eliminate the parallel plate waveguide mode [2], however this negates the cost advantage of CPW over microstrip. Another alternative is to terminate the semi-infinite ground planes of the CPW so that the total width of the transmission line is less than $\lambda_d/4$ for moderate to wide strip and slot widths and $\lambda_d/2$ for narrowstrip and slot widths [3]. This new transmission line is called Finite Ground Coplanar (FGC) waveguide and

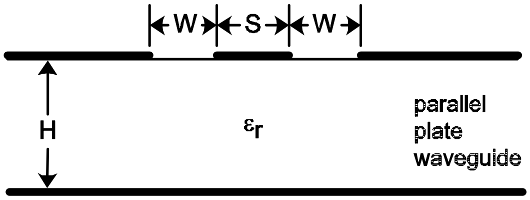

Figure 1: Coplanar Waveguide (CPW).

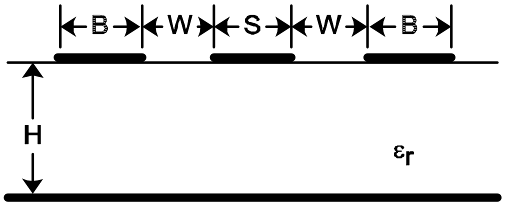

Figure 2: Finite Ground Coplanar (FGC) waveguide.

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is shown in Figure 2. If the ground planes of FGC have approximately the same width as the center strip, FGC may be thought of as a two wire transmission line, Thus, distributed circuit elements such as series stubs [4], [5] and lumped elements such as MIM capacitors and thin film resistors [6] may be implemented in the ground strips as well as the center strip. Thin ground strips also create surface area on the substrate for integrating chip capacitors, resistors, and other surface mount devices to create a more compact circuit.

Coupling between adjacent transmission lines increases the noise figure and leads to spurious resonances in microwave circuits. Therefore, coupling must be kept as low as possible. Typically, this is achieved by maintaining a wide separation between transmission lines and circuit elements, but this is not possible when circuit compactness is desired. Thus, understanding the coupling characteristics of transmission lines comprising a circuit is critical. Although coupling between adjacent CPW lines has been modeled [7], no characterization of the coupling characteristics of FGC has been reported. In this paper, a two Dimensional-Finite Difference Time Domain (2D-FDTD) analysis and experimental measurements of the coupling between adjacent FGC lines are presented as a function of the ground plane width, B, the line to line separation, D, and the spacing between the center lines of two FGC lines, C, as shown in Figure 3.

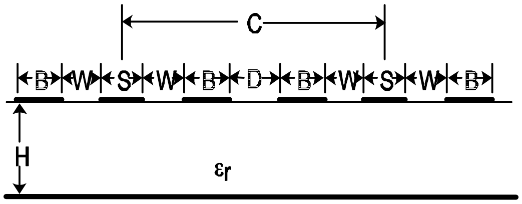

Figure 3: Coupled finite ground coplanar waveguides.

The FGC circuits are fabricated on double side polished Si wafers with a resistivity of 2500 Ω-cm and a thickness, H, of 411 μm. Lift-off processing is used to define the metal lines which consist of 0.02 μm of Ti and 1.5 μm of Au. The lines have a center strip conductor width, S, and slot width, W, of 25 μm. No air bridges or no via holes are used to eliminate the slot line and microstrip modes, respectively.

Measurement Technique

Measurements are made using a vector network analyzer and microwave probes. A full Through-Reflect-Line (TRL) calibration [8] is performed using calibration standards fabricated on the wafer with the reference planes established at the center of the through line. The reference impedance is determined by the characteristic impedance of the delay lines which is approximately 59 Ω for the FGC lines used here. The measured coupling is between two FGC lines with one port of each line terminated in a short circuit as shown in Figure 4. The coupling length, L, is 12000 μm. The attenuation through the 12000 μm of FGC is mathematically removed after the measurements are made.

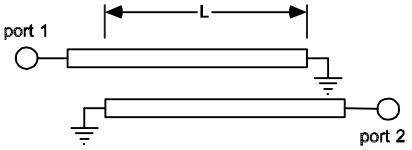

Figure 4: Schematic of coupled finite ground coplanar waveguides used in measurements.

Application of FDTD Method

For the theoretical analysis of the coupled FGC waveguides with S=W=25 μm and H=411 μm, the FDTD method [9] is employed as outlined in [3]. The propagation constant β for the simulations has values of 100 and 500 which corresponds to frequencies of 1.95 and 9.75 GHz, respectively. The coupling coefficient has been calculated by exciting the CPW mode in one of the FGC lines and sampling the tangential electric fields of the coupled FGC line. The tangential electric field has components of the CPW and the parasitic slotline modes. To extract the CPW mode, the field is probed at two points symmetrical with respect to the center of the coupled FGC. Based on these two observations, the even and odd parts of the electric field distribution are determined and the odd component is used to determine the coupling coefficient.

Results

The coupling between two FGC lines as a function of the ground plane width, B, and line separation, D, determined by the 2D-FDTD method and experimentally measured are shown in Figures 5 and 6, respectively. It is seen that the coupling decreases as B and D increases, and the coupling saturates when B and D become large. Figures 7 and 8 show the coupling as a function of the ground plane width and the center to center line spacing determined theoretically and experimentally respectively. It is seen that for a given spacing between the center lines of two FGC lines, the coupling is lower when B is smaller. Therefore, to minimize coupling between FGC lines, it is advantageous to have a thinner ground plane width and larger D for a specified center to center spacing.

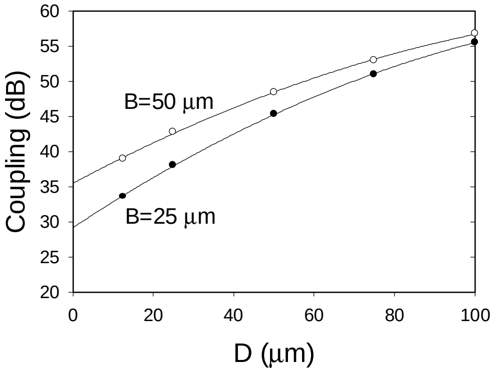

Figure 5: Coupling between Finite Ground Coplanar waveguides as a function of B and D determined by the 2D-FDTD method.

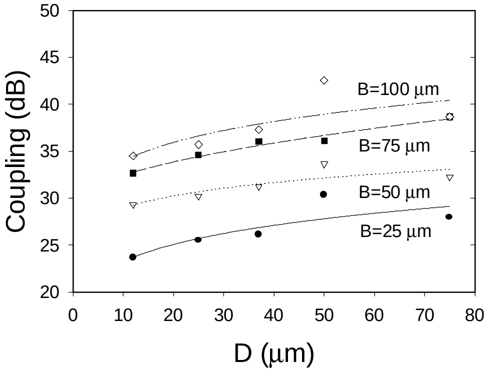

Figure 6: Measured coupling between Finite Ground Coplanar waveguides as a function of B and D.

Although the measured and theoretically determined coupling lead to the same qualitative conclusions, they do not quantitatively correspond well with each other. It is believed that this is due to several factors in the measurements. First, there is a strong slotline mode excited in the coupled FGC line that is not shorted by airbridges. This parasitic mode couples to the CPW mode at the microwave probes and thus influences the measured coupling. Second, the discontinuities in the FGC lines excite surface wave modes in the Si substrate that may couple to the second FGC line. The surface wave mode coupling increases the noise floor and thus causes the measured coupling to saturate at a lower level than it otherwise would. Both of these issues are under investigation.

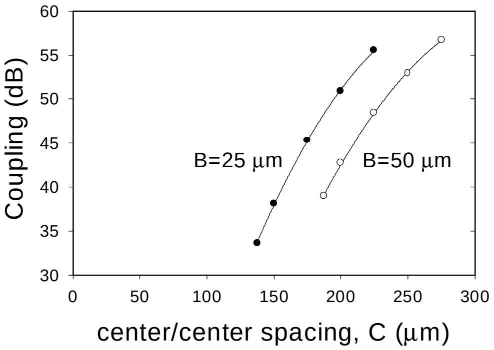

Figure 7: Coupling between Finite Ground Coplanar waveguides as a function of B and C determined by the 2D-FDTD method.

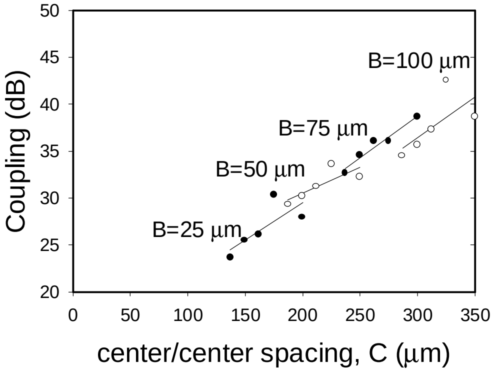

Figure 8: Measured coupling between Finite Ground Coplanar waveguides as a function of B and C.

Conclusions

The coupling between adjacent finite ground coplanar waveguides has been characterized for the first time through a two dimensional-finite difference time domain method and experimentally. The results show that the coupling decreases as the ground plane width and the separation between lines increases until a point where the coupling saturates. Furthermore, it is shown that for a given center to center line spacing, the coupling between two FGC lines is lower when the ground plane width is smaller. Thus, FGC with narrow ground planes have lower coupling.

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